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Research Proposal Letter for Ph.D. Degree

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8.Title of Research Project	**:**	**COMPARATIVE BIO-EFFICACY OF HERBICIDES FOR WEED MANAGEMENT IN *RABI* MAIZE AND RESIDUAL EFFECT ON SUCCEEDING SUMMER BLACK GRAM**

9. Introduction

Maize (*Zea mays* L.*)* is taken into consideration as the queen of cereals and is of huge significance, next to rice and wheat, in agriculture at global level. Its production potential is quite high and no other grain on the planet has such enormous potential. Its multiple uses as fodder, feed, food and a raw substance for several industrial products make it extremely valuable on global scale. Currently, 193.7 million hectares of land is used to grow over 1146.9 million tonnes of maize in 170 different countries with a productivity rate of 5.75 t/ha on average (FAOSTAT, 2020). Over 35% of the world's maize is produced in the United States. China, Mexico, Brazil, India and Argentina are other producers. In India, the rainy and winter seasons are the two main times for maize cultivation. *Kharif* maize accounts for about 83% of the country's total area, while *rabi* maize makes up 17% (Singh *et al*. 2022). Major maize growing states in India are Karnataka,

Madhya Pradesh, Bihar, Tamil Nadu, Telangana, Maharashtra and Andhra Pradesh (APEDA, 2023-24). Bihar, Andhra Pradesh and Tamil Nadu are states that produce *rabi* maize crop. Tamil Nadu produces 40% crop in *rabi* (Yaqoub, M. 2021).

Production of maize in Gujarat is 6.82 lakh tonnes and productivity of 1658 kg/ha over an area of 4.11 lakh hectares (Anonymous, 2018). Dahod, Panchmahal, Vadodara, Sabarkantha, Kheda, Banaskantha, Bharuch, Anand and Dang are the major districts in Gujarat that grow maize.

Maize has importance because of its variety of uses. It serves as both human nutrition and feed for livestock. Corn is used as feed directly. Maize can be converted into a number of foods, particularly "Mexican foods" cooked with alkali and popped snack products. It can also be divided into industrial and food ingredients by wet or dry milling. One of the main components of the maize kernel, starch, is utilized in both food and industrial products. Some of the industrial products are oils, flour, culinary sweetness, alcoholic drinks, cosmetics and biofuel. Maize grains contain 67-72% starch, 12-15% moisture, 8-12 % protein, 2-4% fat, 2-3% fibre and around 1.5% minerals (Kaul *et al.* 2019). For consumption as food, the starch is also converted into glucose and fructose. For use as fuel or in drinks, glucose can ferment to produce ethanol. Both humans and animals can benefit from consuming maize (Yaqoub, M. 2021).

Maize is a C_4 plant and it has high photosynthetic efficiency. Maize crop encounters various kinds of stress during crop period, which might be due to abiotic or biotic factors. During the entire crop growth period, infestation of biotic agents at different stages of maize has their influence on the whole package of practices directly or indirectly. Insect-pest, pathogens, weeds, rodents etc. are some of the biotic agents found. Among these weeds are major factors affecting crop growth, development and economic yield. "Weeds are the unwanted plants that do not have their fixed place and may grow with crop plants and hamper the survival of crop". They are fast growing, hardy in nature and can survive under severe climatic conditions and very little availability or absence of soil moisture and nutrients. Different kinds of weeds (monocot, dicot and sedges) are found.

Since maize is a widely spaced crop, it frequently experiences severe weed competition and weed infestations, which result in high production losses ranging from 28-100% (Patel *et al*. 2006). Mishra, (1997) reported that 40-60% yield reduction of maize, depending on the type of weed flora and their intensity. The critical period of crop weed competition is the time period from sowing up to which crop has to be maintained in a weed-free environment for remunerative crop

production. During this period, weeds compete with crops for moisture, nutrients, space and light. Weeds must be controlled during this period. If not done, they can cause huge growth reduction, which cannot be recovered at later stage. Norsworthy and Oliveira (2004) reported that the critical period of crop-weed competition in maize started at 8 to 9 days and ended at 45-53 days after corn emergence. Weed infestation is a serious challenge for maize cultivators in our country; thus, the maximum reduction in the production is noticed from germination to 45 DAS.

Weed management is the year-round process that maintains the weed population below a threshold level. There are several methods of weed management *viz.*, cultural methods, physical methods and chemical methods that are followed. Among the cultural methods, selection of crop variety, sowing time and method, seed rate etc. are adopted. In physical methods, hoeing, hand weeding, inter-cultivation etc are the most popular methods of weed control in India. These are the oldest and most effective methods against many weeds. However, they are tedious, time consuming and laborious.

In order to overcome this, chemical-based methods have become widely utilized to manage weeds in maize. In general, herbicides are used for reducing weed infestation. These show higher efficiency as when they applied at the correct time, the correct dose and the correct molecule. A dose that is too high could pollute the environment, while a dose that is too low might not be effective at all. In addition, they lead to human health issues such as respiratory difficulties, skin irritation and itching. Excessive herbicide dosages may sometimes harm crops by having phytotoxic effects. Herbicides may also show residual effects on succeeding crops. Pyroxasulfone is a widely used preemergent herbicide for weed control in various crops. However, moderate to high soil persistence of pyroxasulfone can cause phytotoxicity to succeeding crops and disrupt soil microbial communities (Kaur *et al*. 2025). In order to identify the phytotoxic effect and residual effect of applied herbicides, the succeeding summer black gram is selected.

Black gram (*Vigna mungo* L. Hepper) is commonly known as urd, uradbean, mashbean or minapapappu, which is one of the most assertive pulse crops cultivated worldwide in tropical and subtropical regions. It belongs to leguminaceae family. It is most essential short duration legume crop utilized as a food, fodder, soil conservation and integrated farming system. The crop is resistant to adverse climatic conditions and improves the soil fertility by fixing atmospheric nitrogen in the soil. Black gram plays a vital role in the Indian diet, as it contains vegetable protein and supplements to cereal-based diet. It contains about 26% protein, which is almost three times that of

cereals and other minerals and vitamins. It contains 59.6% carbohydrates, 1.4% fat, 3.2% minerals with 154 mg calcium, 9.1 mg iron and 38 mg beta-carotene per 100 grams of black gram.

Black gram is grown in the entire year in all seasons as *kharif* crop, rice fallow crop and *rabi* crop. The major uradbean growing states of India are Madhya Pradesh, Andhra Pradesh, Tamil Nadu, Uttar Pradesh and Maharashtra. In India, black gram is grown in an area of 4.53 million hectares with a production of 2.08 million tonnes and an average productivity of 459 kg/ha during 2019-20. In Gujarat, Black gram is cultivated in an area of 0.99 lakh hectares with a total production of 0.73 lakh tonnes and average productivity of 737 kg/ha during 2019-20 (Anonymous, 2020).

10. Practical Utility of the Research Project

Numerous factors, such as diseases, pests and weeds, have an impact on maize productivity. One of the main issues is weeds cause problems. Compared to the rainy season, the type of weed problem in *rabi* maize is very different. Weeds typically appear in *rabi* maize after the initial irrigation. Weeds grow more when row spacing is wider and fertilizer and irrigation are used liberally (Porwal, 2000). Herbicides are primarily used to suppress or eradicate weeds, which permits the crop to grow freely and improves production. A more robust agricultural system is eventually achieved as a result of improved resource management, more profitable maize production and more sustainable farming methods.

Too far, very little systematic study has been conducted to assess the effectiveness of herbicides in controlling weeds in *rabi* maize and their residual effect on succeeding summer black gram in this region. In light of the previously mentioned facts, a field experiment will be carried out at the Instructional Farm, Department of Agronomy, College of Agriculture, JAU, Junagadh-362001, during *rabi* season of 2025-26 and 2026-27.

11. Objectives

1. To study the effect of different herbicides for weed control in *rabi* maize
2. To study the effect of different herbicides on growth and yield of *rabi* maize
3. To assess phytotoxicity effect of herbicides on maize
4. To assess the residual effect of herbicides on black gram
5. To work out the economics of different treatments

12. Review of Literature

Crop productivity is a dynamic phenomenon that depends on a wide range of exogenous and endogenous factors. The implementation of appropriate agro-techniques may enhance it. Weed control is one of the many agronomic aspects that

contribute to the increased productivity of any crop. It is crucial for harvesting the potential production of maize under diverse agro-climatic conditions. There are numerous herbicides available for controlling weeds in maize, but the type of weed, application rates and timing may all influence how effective an herbicide is.

12.1 Weed flora

Weed flora associated with crops mostly depend upon the agro-climatic conditions, soil type, season and competing ability of crop and crop management practices.

Kannan and Chinnagounder (2014) noticed some of the weeds at the experimental field of maize in *kharif* season. Weeds such as *Cleome gynandra, Datura stramonium, Digera arvensis, Physalis minima, Trianthema portulacastrum* and *Corchorus olitorius.* The dominant grass weeds were *Setaria verticillate* and *Cynodon dactylon. Cyperus rotundus* was the only sedge present in the experimental field.

Barad *et al.* (2016) took an experiment on maize at Junagadh during *rabi* 2013-14 and observed monocot weeds (*Echinochloa colona, Brachiaria spp., Asphodelus tenuifolius, Indigofera glandulosa*), dicot weeds (*Launaea nudicaulis, Amaranthus viridis, Physalis minima, Digera arvensis, Chenopodium album*) and sedges (*Cyperus rotundus*).

Kakade *et al*. (2016) conducted research in *kharif* maize and observed weed species such as *Euphorbia hirta, Phyllanthus niruri, Tridax procumbens, Xanthium strumarium, Celosia argentea, Euphorbia geniculata, Parthenium hysterophorus, Alternanthera triandra, Digera arvensis, Amaranthus viridis, Commelina benghalensisynodon dactylon* and *Cyperus rotundus*.

Ram *et al*. (2017) took an experiment in *rabi* maize at Hyderabad and found several weed species such as *Trianthema portulacastrum, Trichodesma indicum, Parthenium hysterophorus, Melilotus alba, Digera arvensis, Dactyloctenium aegyptium, Cyperus rotundus, Cynodon dactylon, Commelina benghalensis Chenopodium album, Amaranthus polygamus and Eragrostis cilianensis.*

Soren *et al*. (2018) conducted a field experiment on maize during the *rabi* season of 2015-16 and 2016-17 at Purulia in West Bengal. The predominant weed flora noticed by them in the experimental plot were *Portulaca oleracea, Trianthema monogyna, Physalis minima, Euphorbia hirta, Digera arvensis, Cyperus iria, Cyperus rotundus, Echinochloa colona, Digitaria sanguinalis, Eleusine indica, Brachiaria mutica, Amaranthus viridis, Chenopodium album, Fumaria parviflora, Alternanthera philoxeroides, Phyllanthus niruri, Boerhavia diffusa* and *Eclipta alba.*

Chandrakanth *et al*. (2019) carried out an experiment on *rabi* maize at the Regional Agricultural Research Station, Lam, Guntur, Andhra Pradesh. They observed *Dinebra retroflexa* as a dominant monocot weed, *Trianthema portulacastrum* and *Phyllanthus madaraspatanense* as dominant dicot weeds and *Cyperus rotundus* as a dominant sedge.

Kakade *et al.* (2020) experimented at Akola on *kharif* maize in 2016-2018. They observed *Digera arvensis, Cynodon dactylon, Tridax procumbens, Ageratum conyzoides, Bidens pilosa, Euphorbia hirta, Cyperus rotundus, Xanthium strumarium, Parthenium hysterophorus, Euphorbia geniculata, Abutilon indicum, Abelmoschus moschatus, Boerhavia diffusa, Calotropis gigantea, Mimosa pudica, Alternanthera triandra, Phyllanthus niruri, Celosia argentea, Portulaca oleracea, Lagasca mollis, Amaranthus viridis, Dinebra arabica, Panicum spp., Commelina benghalensis, Ischaemum pilosum, Digitaria sanguinalis, Dinebra retroflexa, Poa annua, Cyanotis axillaris* etc. weed species during the experimental period.

Kaur *et al*. (2020) at Ludhiana and Gurdaspur *kharif* maize in 2017 and observed weed flora such as *Acrachne racemosa*, *Commelina benghalensis*, *Cyperus compressus, Cyperus rotundus*, *Dactyloctenium aegyptium*, *Digitaria sanguinalis*, *Echinochloa colona*, *Eleusine indica* and *Eragrostis tenella* as monocots, *Trianthema portulacastrum, Portulaca oleracea, Digera arvensis and Mollugo nudicaulis* as dicots.

Rani *et al.* (2020) conducted research work on *rabi* maize at S.V. Agricultural College, Tirupati and found predominant weed flora, which were *Brachiaria ramosa, Cyanodon dactylon, Dactyloctenium aegyptium, Digitaria sanguinalis, Cyperus rotundus, Boerhavia erecta, Borreria hispida, Celosia argentea, Cleome viscosa, Clitoria ternata, Commelina benghalensis, Corchorus aestuans, Digera arvensis, Euphorbia hirta, Phyllanthus niruri, Trichodesma indicum* and *Tridax procumbens*.

Chaudhari *et al.* (2023) experimented at the AICRP weed farm, Anand Agricultural University in *rabi* maize. They founded fourteen weed species, of which, *Eleusine indica, Digitaria sanguinalis, Setaria glauca, Eragrostis major, Dactyloctenium aegyptium, Asphodelus tenuifolius, Commelina benghalensis* were monocot weeds and *Chenopodium album, Chenopodium murale, Digera arvensis, Phyllanthus niruri, Melilotus alba, Boerhavia erecta and Oldenlandia umbellate* were dicot weeds.

12.2 Effect of herbicides on weeds

Susheela *et al*. (2015) in maize recommended pre-emergence application of atrazine at 1.0 kg/ha *fb* topramezone at 40 mL/ha as post-emergence spray for controlling various weeds in maize under situations of scarcity and non-availability of labour.

Swetha *et al*. (2015) from their research work on *kharif* maize concluded that herbicidal application of topramezone + atrazine (25.2 + 250 g/ ha) + adjuvant as PoE showed low weed dry biomass and weed count of grassy, BLWs and sedges at 20 DAS.

Singh *et al*. (2017) carried out a field experiment at Regional Research Station, CCSHAU, Haryana during *spring* season of 2016 on maize and concluded that alachlor 2000 g/ha as pre-emergence *fb* tembotrione 120 g/ha at 25 DAS + surfactant achieved excellent weed suppression, with the lowest weed density and dry matter accumulation at 40, 60 and 80 DAS. It effectively controlled a wide range of weeds, making it the most consistent performer among all treatments.

Chandrakanth *et al.* (2019) in *rabi* maize reported that among the practices of chemical weed management, application of tembotrione @ 100 g a.i./ha (PoE) at 20 DAS showed the minimum weed density and maximum WCE at 50 DAS.

Sabiry and Babu (2019) carried out an experiment in *kharif* maize in 2014 at Dharwad. From the findings it was examined that herbicide mixtures *viz*., topramezone 12.5 g/ha + atrazine 625 g/ha and topramezone 12.5 g/ha + 2,4-D 500 g/ha significantly lowered total weed density (8.67 and 11.67/0.5 m^2 respectively) and weed dry biomass (5.59 and 6.60 g/0.5 m^2 respectively) which were at par with recommended practice at 30 DAS.

Ghrasiram *et al.* (2020) from the experiment conducted on *kharif* maize at RPCAU, Pusa, Bihar noted that by applying atrazine @ 1.0 kg/ha *fb* tembotrione @ 0.120 kg/ha lowered the count of grassy weeds, BLWs and total weeds and their dry weight compared to all the other weed control treatments. This treatment had WCE of 78% with weed index 2.7%.

Kakade *et al.* (2020) noted in *kharif* maize that herbicidal treatment of atrazine 0.5 kg/ha *fb* tembotrione 0.120 kg/ha PoE at 20 DAS produced less weed count and weed dry matter than rest of herbicides. Higher valued weed control efficiency and lower valued weed index were also recorded under the same.

Rasool *et al*. (2020) conducted research work during 2017-18 at Kashmir, concluded that to evaluate the impact of post and pre-emergence herbicides application on weed growth and yield of *kharif* maize. From their experiment, it was

noted that by applying atrazine 1.0 kg/ha (PE) efficient control of weeds in maize crop was achieved. Also, showing the highest WCE with values ranging from 75.52-83.10% except for *Cyperus species* with only 2.84% efficiency.

Kumar and Boraiah (2021) carried out an experiment during the summer of 2020 at Zonal Agricultural Research Station, UAS, GKVK, Bangalore to study the bio-efficacy of pyroxasulfone for controlling weeds in summer maize. Application of pyroxasulfone at its different dosages significantly influenced the weed density and weed dry weight of broad-leaved weeds, grasses and sedges at 15, 30 and 45 days after herbicide treatment in summer maize.

Bahrami *et al*. (2023) conducted a field experiment at Junagadh on *rabi* maize on clay soil. From the results it was concluded that, application of atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS and atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS reduced total number of weeds at 30, 60 DAS and at harvest, dry weight of weeds and weed index. Higher weed control efficiency was also noticed under the same treatments, except HW at 15 and 30 DAS and weed free situation.

Sachan *et al*. (2023) at Kanpur in *kharif* maize in 2021 under clay soil and observed that application of atrazine 0.50 kg/ha *fb* tembotrione 0.120 kg/ha PoE at 20 DAS registered lower weed count (per meter square) at 40, 60, 80 DAS and at harvest with the value of 4.69, 6.07, 6.27 and 5.59 respectively. Similarly, lower values of weed dry accumulation and weed index and higher value of weed control efficiency at 40, 60, 80 DAS and at harvest were observed.

Sahoo *et al*. (2024) from their research work during *kharif* seasons of 2019 and 2020 on maize concluded that hand weeding performed well in terms of less weed density and dry matter of monocots, dicots and sedges and higher weed control efficiency at 60 DAS. Among different herbicide mixtures, tembotrione + atrazine 1500 g/ha was found to be effective in suppressing the growth of weeds.

Singh *et al.* (2024) carried out an experiment at CSA Kanpur on maize during *kharif* 2021 and concluded that the herbicide mesotrione + atrazine was highly effective against major weeds. The 1.750 kg a.i./ha dose provided the highest weed control efficiency (90%) and lowest weed density across all growth stages, making it the most efficient for suppression of weeds.

Begum *et al*. (2025) carried out an experiment in *kharif* maize at the Agriculture Research Station, Karimnagar. They concluded that among various weed control tactics, application of pyroxasulfone @ 0.1275 kg a.i./ha as PE *fb* tembotrione

@ 0.12 kg a.i./ha as PoE at 20 DAS *fb* HW at 40 DAS reduced weed population and weed dry weight. Also, the highest weed control efficiency was recorded at 60 DAS.

12.3 Effect on growth, yield attributes and yield

Ahmed and Susheela (2012) carried out a field experiment on maize on sandy loam soil at Hyderabad during *kharif* 2010. From the findings it was concluded that plant height, no. of grains per cob, no. of seed rows per cob and 100-grain weight were highest in IC at 20 DAS *fb* hand-weeding at 30 DAS, which was at par with atrazine 1.0 kg/ha *fb* IC at 20 DAS and atrazine 1.0 kg/ha *fb* topramezone 40 g/ha at 25 DAS. The highest grain yield was achieved with IC at 20 DAS *fb* HW at 30 DAS, atrazine 1.0 kg/ha *fb* IC at 20 DAS and atrazine 1.0 kg/ha *fb* topramezone 40 g/ha at 25 DAS, which were on par with each other. Stover yield followed the same trend as that of grain yield.

Swetha *et al*. (2015) experimented during *kharif*, 2014 at Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad on sandy loam soil and reported that hand weeding at 20 and 40 DAS showed maximum grain (6.58 t/ha) and stover yield (8.04 t/ha). It was closely followed by application of topramezone + atrazine (25.2 + 250 g/ ha) + adjuvant as PoE with higher grain (6.44 t/ha) and stover yield (7.60 t/ha).

Singh *et al*. (2017), in a field experiment at Haryana during *spring* season 2016 in maize concluded that combination of alachlor 2000 g/ha as PRE followed by tembotrione 120 g/ha + surfactant as significantly improved maize growth and yield. This treatment promoted better weed-free conditions throughout the crop cycle, resulting in enhanced crop performance and yield attributes.

Gharsiram *et al.* (2020) took experiment on *kharif* maize and noted that applying atrazine @ 1.0 kg/ha followed by tembotrione @ 0.120 kg/ha gave higher cob girth (14.1 cm), cob length (15.8 cm), 100 seed weight (314 g), grain yield (6.24 t/ha) and straw yield (8.61 t/ha).

Kakade *et al.* (2020) conducted a research work and concluded that among herbicidal treatments, maximum cob weight at harvest (132.18 g), grain weight (84.10 g), test weight (26.15 g) and pooled grain yield (4.33 t/ha) were recorded with treatment of atrazine 0.5 kg/ha *fb* tembotrione 0.120 kg/ha PoE at 20 DAS. It found at par with atrazine 1.0 kg/ha as PE.

Singh *et al*. (2020) conducted the experiment in *kharif* and *rabi* seasons of 2015 and 2016 in maize. The findings showed that weed-free conditions produced the maximum maize grain yields (6505 and 6903 kg/ha) in 2015 and 2016. However, alachlor 2000 g/ha pre followed by tembotrione 120 g/ha + surfactant at 35 DAS

provided comparable yield (6380 and 6816 kg/ha). This treatment effectively supported crop growth by minimizing weed competition.

Kumar and Boraiah (2021) conducted an experiment on the assessment of bioefficacy of novel pyroxasulfone for controlling weeds in summer maize. Results revealed that among various herbicidal treatments, higher plant height at harvest (161 cm), cob length (17.8 cm), cob girth (16.1 cm), kernel yield per plant (136.4 g), kernel yield (5.73 t/ha) and stover yield (7.22 t/ha) were observed under treatment atrazine 50% WP 2000 g/ha. It was followed by pyroxasulfone 85% WG 125 g/ha with kernel (5.54 t/ha) and stover yield (6.94 t/ha).

Kumawat *et al.* (2021) conducted a field experiment during *kharif* in maize in 2018-19. From this, they concluded that superior yield components were found *viz.,* cob length, number of cobs/plants, cob girth, number of grains/cobs, cob weight, 100 grain weight, including high biological yield and seed yield in weed free treatment. Among treatments of herbicides, topramezone + atrazine @ 35 + 250 g/ha was found superior in aspects of growth and yield. It was followed by application of tembotrione + atrazine 1250 g/ha.

Bahrami *et al*. (2023), experimented was on medium black calcareous soil at Junagadh (Gujarat) during *rabi* season of 2019-20 to study the bioefficacy of herbicides and their mixtures for weed management in *rabi* maize. Results depicted that weed-free check and HW at 15 & 30 DAS were superior among all treatments in respect of growth and yield. Application of atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS, gave higher growth among all chemical methods. Higher grain (3956 kg/ha) and stover yield (5758 kg/ha) were also observed. The next best chemical method was atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS.

Sachan *et al*. (2023) conducted research work on maize in *kharif* season at Kanpur and concluded that under treatment *i.e.* atrazine 0.50 kg/ha *fb* tembotrione 0.120 kg/ha PoE at 20 DAS, increased crop yield due to efficient control over weeds.

Sahoo *et al*. (2024) from their research work during *kharif* seasons of 2019 and 2020 on maize, concluded that among all chemical treatments, application of tembotrione + atrazine 1500 g/ha recorded higher grain (44.41 q/ha) and stover (47.18 q/ha) yield.

Sepat and Singh (2024) carried an experiment on maize during *kharif* during 2021 and 2022 at ICAR-Indian Institute of Maize Research, Ladhowal, Ludhiana and reported that both application of pyroxasulfone as PE *fb* topramezone as PoE and pyroxasulfone as PE *fb* tembotrione as PoE were efficient in giving higher no. of

grains per cob, weight of cob and grain weight per cob. In year 2021 and 2022 the former gave grain (7.05 and 7.17 t/ha) and stover yield (8.13 and 8.37 t/ha), while the latter gave grain (6.97 and 6.96 t/ha) and stover yield (8.27 and 8.17 t/ha).

12.4 Phytotoxic symptoms of herbicides on crop

Kumar *et al*. (2017), during *kharif* season of 2014 and 2015 at CSKHPKV, Palampur in maize concluded that tembotrione didn't cause phytotoxic effect on maize regarding epinasty, necrotic symptoms, hyponasty, stunted growth and wilting at 7, 14 and 28 days after the spray due to selective nature of herbicide on maize.

Kurre *et al*. (2017) conducted a field experiment during *kharif* 2015 at RPCAU, Bihar on maize. It was noticed that application of halosulfuron methyl, atrazine and pendimethalin were safe for maize, with no phytotoxic effects observed. These herbicides, applied alone or in combinations, effectively supported crop growth and yield without causing visible crop injury, indicating their suitability for integrated weed management in maize.

Swetha *et al*. (2018) conducted an experiment in Hyderabad in *kharif* maize in 2014 under sandy loam soil condition. From the findings, it was confirmed that none of the tested herbicide treatments, including atrazine, topramezone, tembotrione and their combinations with adjuvants, exhibited none phytotoxic symptoms like epinasty, necrosis, stunting or wilting in maize. This indicates a high level of crop selectivity and safety for all evaluated formulations and mixtures.

Yadav *et al.* (2018) evaluated bio-efficacy of tembotrione for PoE control of mixed weed flora in maize during the rainy seasons 2009-2015 at Karnal (Haryana). Tembotrione had no residual effects on wheat grown later. Tembotrione residues at 120 g/ha + S 1000 mL/ha and 240 g/ha + S 1000 mL/ha were also below detectable limit in raw cobs, grains, and straw of maize as well as soil in 2015.

Patel *et al*. (2019) conducted an experiment on maize on loamy sand textured soil during *kharif* of year 2016-17 and 2017-18 at AICRP on Weed Management Farm, AAU, Anand. They concluded that applying atrazine alone and tank mixing with topramezone, tembotrione not caused any injury on the crop from 7-35 DAS.

Sharma *et al.* (2019) conducted an experiment on *kharif* maize at CSKHPKV, Palampur and concluded that pre and post emergence application of atrazine alone or combination with 2,4-D, were safe for maize, with no visible phytotoxic symptoms observed at 15 or 30 days after spraying. Additionally, no atrazine residues were detected in soil, grain or stover, confirming the environmental and crop safety of atrazine based weed management in maize.

Kumar and Boraiah (2021) from their study at UAS, Bangalore revealed that pyroxasulfone at doses above 125 g/ha caused noticeable phytotoxic effects in maize, including reduced chlorophyll content, leaf growth, plant height and kernel yield. While 125 g/ha provided satisfactory weed control and yield benefit (21%), higher doses led to a decline in crop performance, indicating that 125 g/ha is the safe threshold for pre-emergent application in summer maize.

Poojitha *et al*. (2021) in *kharif* 2017, conducted a study at UAS, Bengaluru on maize and concluded that none of the new herbicide molecules- including tembotrione, topramezone, dimethenamid-P, halosulfuron methyl and 2,4-D sodium salt didn't cause phytotoxic effect on maize. All treatments were found to be safe for the crop, even when applied at 20 DAS.

12.5 Yield losses due to weeds

Sharma *et al*. (2000) recorded 32.3 to 42.3% of yield loss due to unchecked growth of weeds.

Pandey *et al*. (2002) noticed that monocot weeds exerted maximum competition to the crop, therefore reducing grain yield by 77.4% followed by dicot weeds (44.2%) and sedges (38.2 per cent).

Reddy and Tyagi (2005) revealed from their experiment that in maize due to weeds, yield loss ranged from 40-80%.

Dalley *et al*. (2006) reported that season long weed competition reduced yields by more than 90% in maize.

Isik *et al.* (2006) recorded yield loss by 43% in corn when weeds are allowed to compete with crop from planting to harvest.

Barad (2015), a field experiment was conducted during *rabi* season of 2013 at Junagadh. He recorded 64.27 and 60.31% reduction in grain and fodder yield of popcorn, respectively in unweeded control as compared to weed free condition.

Kakade *et al.* (2016) yield loss occurs up to 33% to complete crop failure due to weed competition in maize.

Kaur *et al.* (2020) conducted an experiment at Ludhiana and Gurdaspur during *kharif* 2017 and observed grain yield loss of 27.93 and 33.26% and stover yield loss of 34.74 and 24.33%, respectively due to uncontrolled weeds.

Mahto *et al.* (2020) carried out a field experiment during *rabi* season of 2017-18 at Varanasi and reported 90.11% reduction in grain yield under unweeded condition.

Kumar and Boraiah (2021) experimented during summer 2020 at Bangalore and reported that weeds caused yield reduction to the tune of 32% in summer maize.

12.6 Effect of herbicides on succeeding crop

Singh *et al*. (2012) conducted a field experiment at Pantnagar during the rainy seasons of 2009 and 2010 and assessed the effectiveness of tembotrione (42% SC) against mixed flora in maize as well as its residual influence on growth and yield of the subsequent mustard crop. Compared to other herbicidal treatments applied either before or after emergence, post-emergence application of tembotrione 120 g/ha combined with surfactant was shown to be the most successful in controlling both grassy and non-grassy weeds. The subsequent mustard crop's development and output showed no residual impacts.

Singh *et al*. (2020) took an experiment during *kharif* and *rabi* season of 2015 and 2016 with maize-wheat cropping sequence at CCSHAU, Haryana. From their findings, they reported that all the applied herbicides (atrazine, 2,4-D, alachlor and tembotrione) in maize crop didn't show any carryover effect on succeeding wheat crop.

Paul *et al*. (2022) took an experiment at Agricultural College and Research Institute, Madurai during *kharif* 2019 to evaluate the residual effect of herbicides used in preceding corn on succeeding black gram. They concluded that application of preceding herbicides, *viz.,* atrazine and tembotrione on maize, did not influence the germination and any phytotoxic residual effect on succeeding black gram.

Lavanya *et al*. (2024), the field experiment was conducted during *kharif* 2018 and 2019 seasons in maize at TNAU, Coimbatore. Application of preceding herbicides (atrazine, pendimethalin, topramezone and tembotrione) on maize did not show the residual effect on succeeding sunflower. In maize-sunflower cropping system, application of atrazine as PE *fb* either topramezone or tembotrione as EPoE in maize registered the lesser residual effect, weed seed bank and recorded the extended weed control compared to the control.

12.7 Economics

Swetha *et al*. (2015) reported that the highest benefit: cost ratio of 3.17 was achieved with tank mix application of topramezone + atrazine at 25.2 + 250 g/ha + MSO as PoE, followed by atrazine as PE *fb* intercultivation at 30 DAS (3.11). They concluded that tank mix application of topramezone (25.2 g/ha) or tembotrione (105 g/ha) with reduced doses of atrazine (250 g/ha) along with adjuvants was effective in control of weeds and resulted in higher yields in *kharif* maize.

Kumar *et al*. (2017) at CSKHPKV, Palampur during *kharif* 2014 and 2015 and concluded that the highest marginal benefit : cost ratio was found with the use of atrazine at 1500 g/ha, owing to its low cost. This was followed by tembotrione 130 g/ha + surfactant at 21 DAS, then by tembotrione 130 g/ha + surfactant at 14 DAS and tembotrione 130 g/ha at 21 DAS in both years. In contrast, the weed-free and farmer's practice treatments recorded lower marginal B:C ratios, likely due to the higher cost of cultivation and weed control measures involved.

Singh *et al*. (2017) carried out a field experiment at Haryana during *spring* season 2016 in maize and concluded that combination of alachlor 2000 g/ha as PRE followed by tembotrione 120 g/ha + surfactant was superior to other treatments, delivering the highest return over variable cost (₹68,205/ha) and the best benefit : cost ratio of 2.41. This indicates strong profitability and cost-efficiency, making it a highly recommended weed management strategy in maize.

Chandrakanth *et al*. (2019) experimented on *rabi* maize at Guntur, Andhra Pradesh and found that maximum net returns and B:C were achieved with application of tembotrione 100 g a.i./ha. Although hand weeding recorded the highest kernel yield, it resulted in minimal net returns and B: C ratio compared to application of tembotrione at 100 g a.i./ha, primarily due to higher cost involved in manual weeding.

Kumawat *et al.* (2021) experimented *kharif* maize in 2018-19. They concluded from economic analysis that herbicidal treatment topramezone + atrazine @ 35 + 250 g/ha found superior in benefit : cost ratio and economic compared to other treatments. Therefore, topramezone + atrazine @ 35 + 250 g/ha herbicide treatment was more beneficial to the farmers in maize crop.

Bahrami *et al*. (2023) observed under *rabi* maize at Junagadh that, application of atrazine 500 g/ha as PE *fb* tembotrione 100 g/ha as PoE at 30 DAS gave the highest net return of ₹45,253/ha and maximum B: C ratio of 2.43 due to efficient weed control and higher productivity. This was followed by atrazine 500 g/ha as PE *fb* topramezone 25 g/ha as PoE at 30 DAS and with net returns of ₹42,224. The lowest net return (₹22,216/ha) and B: C ratio (1.84) were noted in the weedy check.

Chaudhari *et. al*. (2023) at Anand, experimented on *rabi* maize and recorded the economics of different treatment, which indicated that maximum benefit : cost ratio of 2.67 and 2.89 was observed with atrazine + pendimethalin 500 + 250 g/ha (tank-mix) PE during 2019-20 and 2020-21, respectively.

Begum *et al*. (2025) found that weed free treatment (HW at 20 & 40 DAS) in *kharif* maize gave the highest net return (₹93,397/ha) and B:C ratio (2.49) despite of high cost. Pyroxasulfone *fb* tembotrione *fb* HW followed closely with a B:C ratio of

2.48. Other treatments like pyroxasulfone *fb* topramezone, mesotrione + atrazine and topramezone + atrazine were also effective (B:C > 2.2). The weedy check gave the lowest return (₹12,846/ha) and B:C ratio (1.29).

13. Materials and Methods

13.1	**Title of the Experiment**	**:**	Comparative bio-efficacy of herbicides in *Rabi* maize and residual effect on succeeding summer black gram
13.2	**Location**	**:**	Instructional Farm, Department of Agronomy, College of Agriculture, JAU, Junagadh-362001
13.3	**Year and season of experiment**	**:**	*Rabi* 2025-26 and 2026-27
13.4	**Experimental design**	**:**	Randomized Block Design
13.5	**No. of treatments**	**:**	Ten (10)
13.6	**No. of replications**	**:**	Three (3)
13.7	**Spacing**	**:**	60 cm between rows
13.8	**Crop and variety**	**:**	Maize, GAYHM-3
13.9	**Seed rate**	**:**	20 kg/ha
13.10	**Plot size: Gross**	**:**	5.0 m x 3.6 m
13.11	**Plot size: Net**	**:**	4.0 m x 2.4 m
13.12	**Recommended dose of fertilizer**	**:**	100:50:00- N: P_2O_5:K_2O (kg/ha)

Note: As per agronomic practices in black gram

13.13 Treatment details

T. No	Treatment Details

T_1	Atrazine 50% WP 1000 g/ha as PE *fb* IC and HW at 25-30 DAS
T_2	Diuron 80 % WP 800 g/ha as PE *fb* IC and HW at 25-30 DAS
T_3	Pyroxasulfone 85% WG 125 g/ha as PE *fb* IC and HW at 25-30 DAS
T_4	Pyroxasulfone 85% WG 125 g/ha as PE *fb* Topramezone 33.6% SC 25 g/ha at 25-30 DAS
T_5	Pyroxasulfone 85% WG 125 g/ha as PE *fb* Tembotrione 120 g/ha at 25-30 DAS
T_6	Pyroxasulfone 85% WG 125 g/ha as PE *fb* Mesotrione 2.27% w/w + Atrazine 22.7% w/w SC 300 g/ha at 25-30 DAS
T_7	Topramezone 10 g/l + Atrazine 300 g/l SC 775 g/ha as PE
T_8	Tembotrione 9% + Atrazine 45% WG @ (135 + 675) g/ha as PE
T_9	IC and HW at 20 and 40 DAS
T_{10}	Weedy check (control)

13.14 Observations to be recorded

13.14.1 For Main Crop (Maize)

13.14.1.1 Growth, yield attributes and yield

13.14.1.1.1 Growth parameters:

1. Plant population at 15 DAS and at harvest
2. Plant height (cm) at 30, 60 DAS and harvest
3. Leaf area (cm^2/plant) at 30, 60 DAS and harvest
4. Phytotoxicity on crop at 7, 14 and 21 days after herbicide application (0 to 10 scale)

13.14.1.1.2 Yield attributes

1. Length of cob (cm)
2. Girth of cob (cm)
3. Number of grains per cob
4. Weight of grains per cob
5. Test weight (g)

13.14.1.1.3 Yield

1. Grain yield (kg/ha)
2. Stover yield (kg/ha)

13.14.1.1.4 Weed parameters

1. Weed flora
2. Group wise weed count at 30, 60 DAS and harvest.
3. Dry weed weight (kg/ha) at harvest
4. Weed control efficiency at harvest
5. Weed index
6. Herbicide efficiency index
7. Crop resistance index
8. Weed persistence index
9. Weed management index
10. Agronomic management index
11. Integrated weed management index

13.14.2 For succeeding crop (Black gram)

1. Plant population at 15 DAS
2. Plant height (cm) at harvest
3. Dry matter accumulation at 30 DAS (g/plant)
4. Seed and stover yield (kg/ha)
5. Phytotoxicity on crop at emergence, 15 DAS and 30 DAS (0 to 10 scale)

13.14.3 Economics

1. Cost of cultivation (Rs/ha)
2. Gross return (Rs/ha)
3. Net return (Rs/ha)
4. Benefit: Cost Ratio

14. Statistical Analysis

The data will be subjected to statistical analysis by adopting appropriate analysis of variance as described by Gomez and Gomez (1984). Wherever the F values found significant at 5% level of probability, the critical difference (CD) values/DNMRT will be computed for making comparison among the treatment means. In order to establish interrelationship between various components, coefficients of correlation and regression equations will be computed as described by Panse and Sukhatme (1985).

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